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Nathan Huysman[1], Jill M Voorhees[1], Hilary Meyer[2], Eric Krebs[1] and Michael E Barnes[1]*

[1]South Dakota Department of Game, Fish and Parks, McNenny State Fish Hatchery, 19619 Trout Loop, Spearfish, South Dakota 57783, USA

[2]South Dakota Department of Game, Fish and Parks, 20641 South Dakota Hwy 1806, Fort Pierre, South Dakota 57532, USA

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***Corresponding author:** Michael E Barnes, Research Scientist, South Dakota Department of Game, Fish and Parks, McNenny State Fish Hatchery, 19619 Trout Loop, Spearfish, South Dakota 57783, USA, Tel; 605-642-6920; E-mail: mike.barnes@state.sd.us

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Research Article

Timing of Landlocked Fall Chinook Salmon Spawning and Egg Survival

Abstract

Landlocked fall Chinook salmon (*Oncorhynchus tshawytscha*) in Lake Oahe, South Dakota, USA return to a remote spawning station either already having ovulated (ripe) or with the eggs still retained in the ovary (green). This study documented the ovulation status of female salmon upon arrival at the station and recorded subsequent egg survival to determine the possible impact of different frequencies of spawning operations. The ovulation status of forty-one Chinook salmon was determined upon their arrival at the spawning station in October, 2017. Fish that arrived post-ovulation were spawned as soon as possible, and the resulting eggs maintained discretely until the eyed stage of egg development. Fish that arrived pre-ovulation were held at the station and their ovulation status checked three times per week. After ovulation was observed, these fish were spawned as soon as possible as well. There was no significant difference in survival between the eggs of fish that arrived either pre- or post-ovulation at the station, nor from those that were spawned the same day as they returned to the station compared to those that had to wait up to nine days before spawning. There was also no significant difference in egg survival between those fish that were spawned the same day as they were determined to have ovulated, versus those that were spawned up to seven days after ovulation. There was no significant correlation between egg survival and the number of days a female was held post-ovulation, nor between egg survival and the number of days that a female with unknown ovulation timing was held prior to spawning. These results suggest that spawning landlocked fall Chinook salmon in Lake Oahe more than once-per-week is not necessary and will not positively affect egg survival.

Introduction

When ovulation occurs in salmonids, fertile eggs are released from the ovaries into the body cavity [1-3]. During this period of in-vivo storage, eggs remain viable for approximately one week, depending on water temperature [4], after which time fertility will decline [5]. Thus, if artificial spawning occurs too long after ovulation, decreased egg survival will occur [1,6-8].

Ideally, the timing of ovulation of each individual female broodfish would be determined, and frequent artificial spawning events conducted to maximize egg survival. However, the labor, time, and logistics required for such an approach is unrealistic in a production hatchery setting, and practically impossible when feral broodfish are spawned at remote locations. Thus, salmonid spawning events are typically conducted at planned intervals.

The landlocked fall Chinook salmon population (*Oncorhynchus tshawytscha*) in Lake Oahe, South Dakota, USA is entirely dependent on artificial propagation; there is no natural reproduction [9]. Eggs from this population of fish typically exhibit poor hatchery survival [10-12], and overripe eggs (stored in-vivo well past ovulation) are frequently observed [13,14]. Salmon ascend the fish ladder at Whitlocks Spawning Station adjacent to Lake Oahe throughout the October spawning season. Because these are feral fish, the exact time of ovulation for any post-ovulation (ripe) fish ascending the ladder cannot be determined. Spawning operations at the station have historically been scheduled as frequently as twice per week. Because of the cost and labor involved with spawning at this remote facility, decreasing spawning times to only once per week would be highly desirable. The objective of this study was to document the ovulation status of female salmon upon arrival at the spawning station and determine egg survival of the resulting spawns in order to determine the possible impact of spawning only once per week.

Materials and Methods

A total of 41 female landlocked fall Chinook salmon from Lake Oahe, South Dakota, held at Whitlocks Spawning Station (near Gettysburg, South Dakota) were used in this study. Upon arrival at the station during October and November, 2017, the ovulation status of each fish was determined by applying light abdominal pressure. If eggs were released, the female was assumed to have ovulated. If no eggs were released, the female

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was assumed to be in a pre-ovulatory state. The pre-ovulation females were held in a different raceway at the station, and their ovulatory status was checked three times per week (Monday, Wednesday, and Friday). The number of days until ovulation was recorded for each of the females that arrived at the station pre-ovulation.

The spawning of any post-ovulation females at the station occurred on either October 25 or November 1. The spawning process began when the females were anesthetized using a carbon dioxide solution. Eggs from these fish were then expressed into a mesh net pneumatically using compressed oxygen and fertilized in fresh lake water for two minutes utilizing activated milt pooled from two males. Following fertilization, eggs were rinsed with fresh lake water and allowed to water harden for at least one hour. Individual spawns from each female were maintained discretely during the entire spawning process, as well as during subsequent transportation and incubation.

Following water hardening, eggs were transported approximately 4 hours to McNenny State Fish Hatchery, rural Spearfish, South Dakota, USA. Upon arrival at the hatchery, eggs from each spawn were disinfected for 10 minutes with 100 mg/L buffered free iodine (Syndel, Ferndale, Washington USA), inventoried using water displacement [15], and placed into discreet vertical-flow incubation trays (MariSource, Fife, Washington USA). Eggs were incubated in well water (11ºC; total hardness 360 mg/L $CaCO_3$; alkalinity as $CaCO_3$, 210 mg/L; pH 7.6; total dissolved solids 390 mg/L) at 12 L/min throughout incubation. Formalin treatments of 1,667 mg/L were applied daily (37% formaldehyde, 6 to 14% methanol; Paracide-F, Syndel, Ferndale, Washington) for 15 min [15] using a Masterflex model 7524-00 microprocessor peristaltic pump (Cole-Parmer Instrument Company, Vernon Hills, Illinois, USA).

On incubation day 30 (eyed egg stage), dead eggs were removed, and remaining viable eggs were re-inventoried using water displacement [15]. Survival (%) to eyed stage of development was determined by using the following formula:

Survival (%) = 100 x (number of eyed eggs / initial egg number)

All data analysis was done using the SPSS (9.0) statistical analysis program (SPSS, Chicago, Illinois, USA), with significance pre-determined at $p < 0.05$. T-tests were used to compare difference between groups, and regression and correlation analysis was used to ascertain any possible relationships between egg survival and the number of days until a fish ovulated, as well as the number of days a female was held post-ovulation. Percentage data was log transformed to stabilize the variances [16].

Results

There were no significant differences in fish total length, post-spawn weight, egg size, fecundity, or egg survival between those fish that arrived at the station pre-ovulation (green) and those that arrived post-ovulation (ripe) (Table 1). Both groups were also held the same amount of time after ovulation prior to spawning. Egg survival to the eyed stage of development from the fish that were spawned on the same day as they arrived to the spawning station was not significantly different than egg survival from fish held from one-to-nine days at the station prior to spawning (Table 2). Similarly, there was no significant difference in egg survival between those fish that were spawned on the day of ovulation compared to those fish that were spawned up to seven days post-ovulation (Table 3, Figure 1). Lastly, there were no significant correlations between egg survival and the number of days held prior to ovulation (N=41, r^2=0.076, P=0.080), nor between egg survival and the number of days held past ovulation for all females combined (N=41,

Table 1: Mean reproductive characteristics (± SE) for fall Chinook salmon (n=41) that arrived pre-ovulation (green) or post-ovulation (ripe) from Lake Oahe, South Dakota.

Characteristic	Arrived Green	Arrived Ripe
N	10	31
Egg survival to eyed stage (%)	34.49 ± 6.37	25.30 ± 3.42
Length (mm)	681 ± 27	701 ± 16
Post spawn weight (g)	3,113 ± 431	3,492 ± 253
Days held at station past ripe determination	1.60 ± 0.64	1.23 ± 0.36
Egg size (mm)	4.65 ± 0.35	4.14 ± 0.18
Total fecundity	2,506 ± 317	2,667 ± 194

Table 2: Mean reproductive characteristics (± SE) for fall Chinook salmon (n=41) that were spawned on the day of arrival or held in the spawning station from 1 to 9 days waiting to be spawned from Lake Oahe, South Dakota. Means in a row with different superscript letters are significantly different (P<0.05).

Characteristic	Spawned on Arrival	Held to be Spawned
N	19	22
Egg survival to eyed stage (%)	29.64 ± 4.71	25.73 ± 4.00
Length (mm)	691 ± 20	702 ± 19
Post spawn weight (g)	3,329 ± 328	3,460 ± 295
Times handled at spawning station	0.00 ± 0.00[a]	2.64 ± 0.18[b]
Days held in raceway before spawning	0.00 ± 0.00[a]	4.23 ± 0.55[b]
Days held at station past ripe determination	0.00 ± 0.00[a]	2.45 ± 0.46[b]
Egg size (mm)	4.29 ± 0.26	4.24 ± 0.21
Total fecundity	2,733 ± 261	2,536 ± 210

Table 3: Mean reproductive characteristics (± SE) for fall Chinook salmon (n=41) that were spawned on the same day as their ripe determination or waited to be spawned from 1 to 7 days after ovulation from Lake Oahe, South Dakota. Means in a row with different superscript letters are significantly different (P<0.05).

Characteristic	Spawned same-day	Waited to be spawned
N	24	17
Egg survival to eyed stage (%)	30.12 ± 3.77	23.90 ± 5.04
Length (mm)	699 ± 17	694 ± 24
Post spawn weight (g)	3,406 ± 282	3,390 ± 349
Times handled at spawning station	1.33 ± 0.16[a]	2.65 ± 0.21[b]
Egg size (mm)	4.26 ± 0.22	4.27 ± 0.25
Total fecundity	2600 ± 231	2,668 ± 232

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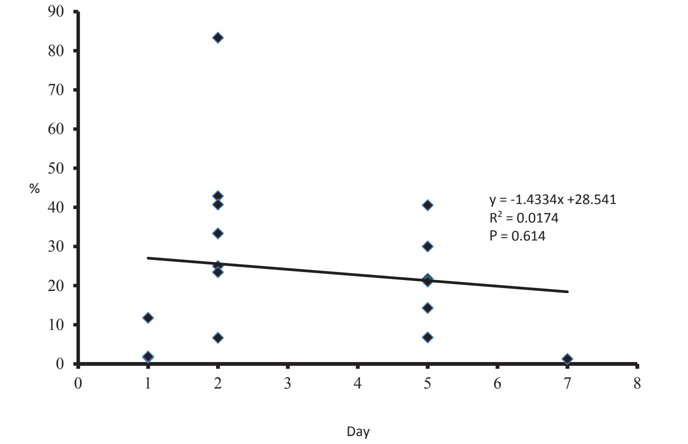

Figure 1: Landlocked fall Chinook salmon egg survival to the eyed stage in relation to the number of days spawned after ovulation.

r^2=0.033, *P*=0.260), females that arrived at the station pre-ovulation (N=10, r^2=0.072, *P*=0.450), or females that arrived post-ovulation (N=31, r^2=0.330, *P*=0.330).

Discussion

The results of this study strongly indicate that spawning landlocked fall Chinook salmon in Lake Oahe more than once per week would likely have minimal effect on egg survival. The lack of any relationships between the amount of time held at the spawning station prior to spawning and egg survival, including for those fish that have already ovulated for an unknown number of days prior to arriving at the station, justifies adopting a weekly spawning routine. Adoption of this standard would not only save labor, but also substantial transportation or other costs associated with bringing spawning crews to a remote location. In addition, weekly spawning would reduce the number of unique salmon lots, improving hatchery rearing efficiencies as well.

The number of days post-ovulation could not be determined for the salmon that arrived at the spawning station already ripe. While it is clear that retaining eggs inside the body cavity for an extended period of time leads to reduced viability [1,5,6,8,17], apparently the salmon that arrived at the station post-ovulation, arrived before a critical amount of time had passed. However, water temperature can impact the amount of time that post-ovulated eggs remain viable [4,18], suggesting that the results of this study may not apply if temperatures are increased. Although the relatively poor homing ability of Lake Oahe Chinook salmon [9] may be why so many salmon arrive at the station having already ovulated, they still apparently arrive at the station in adequate time to maintain egg fertility.

The results of this study also indicate that the relatively low reproductive success of Lake Oahe salmon [10,11,14] cannot be attributed to the frequency of artificial spawning operations. There are numerous other drivers of reproductive success besides spawning frequency likely resulting in the low overall survival of fall Chinook salmon eggs in Lake Oahe, including elevated water temperatures, forage availability, and possibly genetics [10,11,19-21]. Further research attempting to improve Lake Oahe landlocked fall Chinook salmon egg survival should focus on these areas.

Conclusion

The results of this study strongly indicate that spawning landlocked fall Chinook salmon in Lake Oahe more than once-per-week is not necessary and will not positively affect egg survival. Even though a high percentage of females return to the spawning station at an unknown number of days post-ovulation, the possible effects of egg over-ripening are relatively minor compared to the other numerous factors influencing egg survival.

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